A kind of control system in iron roughneck based on the multi-way valve

Yuanchao Zhang, Xinglong Zhu*, Longqin Gao

School of Mechanical Engineering, Yangzhou University, Yangzhou, Jiangsu, 225127, China

*Corresponding Author: xlzhu@yzu.edu.cn

Abstract

In this paper, we introduce the hydraulic principle of iron roughneck about multi-cylinder linkage which adopted the load sensitive and proportional multi-way valve. According to the processes of making-up and breaking-out in iron roughneck, we introduce the pressure principle, position principle and time principle in the control system of iron roughneck, and do some analysis about their advantages and disadvantages. Combining the advantages of this three control methods, we put forward the control system of iron roughneck which synthesizes the pressure principle, position principle and time principle. According to the control system, we select the relevant sensors and do some experiments, the results obtained from the experiments show that the proposed control system has high reliability and utility value.

Keywords: Iron roughneck, Control system, Control method, multi-way valve.

1. Introduction

Human beings depend on oil and gas resource deeply as their lives and social productivity have been improved a lot. At present, the growth of reserves of global oil and gas is sluggish, onshore oil resources crisis is increasingly prominent, the demand for oil and gas in the future in sharp growth makes oil industry in the world face great challenges, therefore, it is urgent to find new reserves as the replacement. After decades of exploration and research, human shift their attentions to the offshore oil resource which aims to the offshore oil resources of low proven level, it is estimated that offshore oil resources take up about 34%~45% percents of total global oil resources, the proven probability is only 30% percents which is still in its early phase of exploration. There are great potentials and good prospects of exploration in Global offshore oil and gas

resources, international offshore petroleum engineering market will continue to be a hot spot in the world economy in quite a long time in the future^(1,2). However, operation costs of offshore drilling platforms is very high, therefore, it becomes particularly important to improve reliability and working efficiency of the drilling platform. Oil-well rig is the key equipment for Offshore drilling platform, however the key to improve work efficiency, achieve well-mechanization and well-automation of the oil-well rig is the rotation screw device of the drilling^(3,4). With the modernization of the drilling process, the automation level of the drilling equipment continue to increase, the rotating screw device of the drilling are keeping upgrading, which develops from manual tongs, hydropneumatic mixed power tongs to the most advanced iron roughneck, it can accomplish the rotation screw connection of the drill pipes, casings and so on, it improves the working efficiency and safety, and it is one of the most important automation equipment of the modern drilling⁽⁵⁾.

Based on load sensitive and proportional multi-way valve in this paper, we design the hydraulic system about multi-cylinder linkage in iron roughneck; through analyzing the pressure principle, position principle and time principle in iron roughneck, we put forward the control system of iron roughneck which synthesizes the pressure principle, position principle and time principle, and do some relevant experiments.

2. The working principle of iron roughneck

Iron roughneck appeared at 70's of the last century, in the production automatic drilling, it was the corollary equipment of drilling machine which was proposed by United States oil equipment producers. As the alternative products of hydraulic power tongs, iron roughneck can complete the work of making-up, breaking-down safely and efficiently, it is an important, automatic and auxiliary

equipment in the modern oil production⁽⁶⁾. Iron roughneck is composed of the mechanical part, the sensing part and the control part, it is a versatile, safe and efficient drill rotating screw device, and through the man-machine interaction system it can complete the processes of making-up and breaking-down, which has advantages of compact structure, high work efficiency, convenient installation and operation, and can be widely applied in onshore drilling platforms and offshore drilling platforms which have complex environment.

Fig.1. Mechanism sketch of arm-type iron roughneck.

The arm-type iron roughneck is mainly composed of the base, supporting pillar, articulated jib, electrical cabinet, and the pliers and so on, as shown in Fig.1. The pliers of the arm-type iron roughneck is divided into upper parts and lower parts, the upper pliers are rotating screw pliers, the lower pliers are clamping pliers and thread-making pliers; the upper pliers and the lower pliers is connected through the connecting frame and one end of the articulated jib.

Iron roughneck is a high efficient rotating screw device, its continuous processes mainly includes automatic making-up process and automatic breaking-out process.

(a) Automatic making-up process

Finding out the centre of the drilling tool automatically through automatic centering device. First, clamping pliers clamp the lower drilling tools tightly, rotating screw pliers clamp the upper drilling tools, 4 synchronous motors of the rotating screw pliers rotate counterclockwise, driving the upper drilling tools rotate clockwise by friction to make the upper and the lower drilling tools screw rapidly. Then, loosen the rotating screw pliers, tread-making pliers clamp the upper drilling tools. At last, the thread-making oil cylinder pull the thread-making pliers to rotate clockwise along the orbit whose center is in the same position with the drilling tool's circle center, and make the upper and the lower drilling tools tighten up, achieving the making-up process.

(b) Automatic breaking-out process

Finding out the centre of the drilling tool automatically through automatic centering device. First, clamping pliers clamp the lower drilling tools tightly; thread-making pliers clamp the upper drilling tools. Then, the piston of thread-making oil cylinder stretch out to push tread-making pliers rotate counterclockwise along the orbit whose center is in the same position with the drilling tool's circle center, achieving the thread-making process. At last, the thread-making pliers loosen, the rotating screw pliers clamp the upper drilling tools, 4 synchronous motors of the rotating screw pliers rotate clockwise, driving the upper drilling tools rotate counterclockwise by friction to make the upper and the lower drilling tools completely out of each other, achieving the breaking-out process.

3. The design of hydraulic system in iron roughneck

Fig.2. The integral hydraulic schematic diagram of iron roughneck

The main processes of iron roughneck consist of

making-up process and breaking-out process, the traditional making-up and breaking-out processes are carried out step by step, and the working efficiency is very low. In this paper, with the purpose of designing the efficient control processes in iron roughneck, we choose the load sensitive and proportional multi-way valve type PSD, which has the advantages of small oil cylinder impulsion, high efficiency, and could achieve multi-cylinder linkage, to make each basic circuit up organically, as shown in Fig. 2. The load sensitive and proportional multi-way valve can work independently with different pressure and speed, and each loop does not influence each other. In order to adapt to the different highest pressure restrictions of different executive components, the overfull pressure of each directional valve can be set separately ⁽⁷⁾.

The load sensitive and proportional multi-way valves are adopted by the hydraulic system of iron roughneck, it could achieve multi-cylinder linkage in the process of automatic making-up and breaking-out to improve its working efficiency.

4. The design of control system in iron roughneck

4.1 The selection of control method

The control system of iron roughneck can adopt the control method in the principle of pressure, location or time, however each control method has its advantages and disadvantages.

(a) Pressure principle

The control method of pressure principle usually adopts pressure transmitter as its control components. Pressure Transmitter is used to measure the pressure of the oil cylinders or the main oil line in iron roughneck, and convert the pressure signal into analog signal whose range is 4 ~ 20mA. Pressure Transmitters mainly includes capacitive pressure transmitter, diffused silicon pressure transmitter, ceramic pressure transmitters and strain gauge pressure transmitters, etc.

The pressure transmitters of iron roughneck are mainly used to measure the real-time pressure of the main oil line or oil cylinders in clamping pliers, thread-making pliers and rotating screw pliers. When the pressure of oil cylinder reaches the set value, stop its movement, the control components for pressure principle in iron roughneck are shown in Table 1. Pressure transmitters not only have the advantages of precise measuring and high efficiency, but

also can protect the drilling tools from damage in the clamping process with high pressure.

Table 1. The control components for pressure principle in iron roughneck

Components of iron rough	Executive components	Feedback control components
Rotaty motor	One hydraulic motor	Two travel switches
Lift oil cylinder	One oil cylinder	Two travel switches
Articulated jib	Two oil cylinders	Two travel switches
Clamping pliers	Two oil cylinders	One pressure transmitter
Thread-making pliers	Two oil cylinders	One pressure transmitter
Rotating screw pliers	Two oil cylinders	One pressure transmitter
Thread-making oil cylinder	One oil cylinder	One pressure transmitter
Rotating screw motors	Four hydraulic motors	One pressure transmitter (One timer)
Main oil line		One pressure transmitter

Some companies install a pressure transmitter in the main oil line of the iron roughneck, and the iron roughneck judges whether the pressure of hydraulic cylinder meets the requirement by measuring the pressure of main oil line and checking whether it reaches the setting value or not. With this method the iron roughneck uses fewer pressure transmitters and the production cost less, but the control precision of the oil cylinder's pressure is low, some casings whose requirements of the clamping force is small are easy to be out of shape; The pressure transmitter of the main oil line can only control one oil cylinder and can't achieve efficient multi-cylinder linkage, leading to low working efficiency seriously.

(b) Position principle

The control method of position principle usually uses travel switch as control component. Travel switch which is one kind of position switch (also called limit switch), it is a type of common low current electric command device. Travel switch open or close the control circuit by the contact action which is caused by the crash of moving components of the manufacturing machine, reaching a certain control purpose. Usually, this kind of switch is used to limit the position or stroke of mechanical movement to make the movement machinery complete a series of actions, according to a certain position or stroke, which contain automatic stop, reverse motion, variable motion, automatic to-and-fro movement and so on.

The travel switches of iron roughneck are mainly installed at the top and bottom of oil cylinder or hydraulic motor, used as a limit switch. The control components for position principle are shown in Table 2. The articulated jib

with multiple travel switches can complete automatically accelerating and decelerating, avoiding collision accident and improving the security of iron roughneck; In the process of automatic cycle control, iron roughneck enter to the next motion by taking advantage of travel switch which could complete automatic transfer of the actions and improving the automaticity of the iron roughneck; The control principle of travel switch has some advantages such as faster response and high control precision. But the arm-type iron roughneck has a compact structure, the oil cylinders which are placed in clamp pliers are not convenient to install travel switches; In the bad working conditions like drilling platform, the travel switches which are placed on the outer are easy to be disturbed by the oil, mud and so on.

Table 2. The control components for position principle in iron roughneck

Components of iron rough	Executive components	Feedback control components
Rotaty motor	One hydraulic motor	Two travel switches
Lift oil cylinder	One oil cylinder	Two travel switches
Articulated jib	Two oil cylinders	Four travel switches
Clamping pliers	Two oil cylinders	Two travel switches
Thread-making pliers	Two oil cylinders	Two travel switches
Rotating screw pliers	Two oil cylinders	Two travel switches
Thread-making oil cylinder	One oil cylinder	Two travel switches
Rotating screw motors	Four hydraulic motors	(One timer)
Main oil line		One pressure transmitter

(c) Time principle

The control method of time principle usually adopts the timer of programmable logic controller (PLC) as control media. PLC is the centre of the iron roughneck's control system, and all the courses of action are controlled by the instructions which are given by PLC. The timer is the most common and basic timing or delay controller in all kinds of PLC, The timer begins to time when the timer is input into actuating signal, then the output circuit comes into being jump change after accurate setting time, to make the output end open or close.

In the control system of Iron roughneck, the method that uses the timer of PLC to control the components is a kind of the most common control method. It has some advantages such as high control precision and fast response speed, the control components for time principle are shown in Table 3. But in the clamping processes of clamping pliers,

thread-making pliers and rotating screw pliers, there are serious shortage for using the timer, because the time is different for each clamping process, so a lot of tests are needed to calibrate the clamping time. If the clamping time is not accurate enough, the pressure of oil cylinder is easy to overtop and make the drilling tools be out of shape.

Table 3. The control components for time principle in iron roughneck

Components of iron rough	Executive components	Feedback control components
Rotaty motor	One hydraulic motor	(Two timers)
Lift oil cylinder	One oil cylinder	(Two timers)
Articulated jib	Two oil cylinders	(Two timers)
Clamping pliers	Two oil cylinders	(Two timers)
Thread-making pliers	Two oil cylinders	(Two timers)
Rotating screw pliers	Two oil cylinders	(Two timers)
Thread-making oil cylinder	One oil cylinder	(Two timers)
Rotating screw motors	Four hydraulic motors	(Two timers)

Through comprehensive analysis and comparison to pressure principle, position principle and time principle, taking the purpose of making the control system efficient and reliable, we come up with the control system of iron roughneck which synthesizes pressure principle, position principle and time principle according to the specific movements of iron roughneck.

The rotation of iron roughneck is actuated by a hydraulic motor, it also needs two travel switches to achieve accurate positioning of the wellhead and mouse hole; The lifting of iron roughneck is actuated by an oil cylinder, it also needs two travel switches as the upper and lower limits of the oil cylinder; The expansion of articulated jib is actuated by two synchronous oil cylinders, it also needs two travel switches as the front and back limits of articulated jib, the articulated jib could complete centering of drilling tools automatically through three ultrasonic sensors; The movements of clamping pliers, thread-making pliers and rotating screw pliers are separately actuated by two oil cylinders, it also separately needs a pressure transmitter to control the pressure of oil cylinder accurately, so as to achieve appropriate clamping force on the drilling tools; The rotating screw motors are composed of four hydraulic motors which are synchronous, it needs a pressure transmitter to control the torque of upper and lower drilling tools accurately in the making-up process, it also needs a timer to make sure than the upper and the lower drilling tools could be completely out of each other in the breaking-out process; The movements of thread-making

oil cylinder are actuated by a oil cylinder and two travel switches which works cooperatively, it needs a pressure transmitter to control the torque of upper and lower drilling tools accurately in the making-up process, if it happens to be jammed in the thread-making process, the system will alarm through a timer; The main oil line installs a pressure transmitter which are used to loosen the clamping pliers, thread-making pliers and rotating screw pliers. The executive components and control components of iron roughneck are shown in Table4.

Table 4. The executive and control components of iron roughneck

Components of iron rough	Executive components	Feedback control components
Rotaty motor	One hydraulic motor	Two travel switches -ST1/ST2
Lift oil cylinder	One oil cylinder	Two travel switches -ST3/ST4
Articulated jib	Two oil cylinders	Two travel switches -ST5/ST6 Three ultrasonic sensors
Clamping pliers	Two oil cylinders	One pressure transmitter-SP1
Thread-making pliers	Two oil cylinders	One pressure transmitter-SP2
Rotating screw pliers	Two oil cylinders	One pressure transmitter-SP3
Thread-making oil cylinder	One oil cylinder	One pressure transmitter-SP4 Two travel switches -ST7/ST8 (One timer-T1)
Rotating screw motors	Four hydraulic motors	One pressure transmitter-SP5 (One timer-T2)
Main oil line		One pressure transmitter-SP6

4.2 The design of control flow about multi-cylinder linkage

According to the control system of iron roughneck which synthesizes pressure principle, position principle and time principle, as well as on the basis of the hydraulic system of iron roughneck which adopted the load sensitive proportional multi-way valve, we designed automatic making-up and breaking-out processes about multi-cylinder linkage.

Automatic making-up process: Automatic centering→Clamp the clamping pliers/Clamp the rotating screw pliers→Rotating screw motors rotate counterclockwise→Loosen the rotating screw pliers/Stretch out the thread-making oil cylinder→Clamp the thread-making pliers→Retract the thread-making oil cylinder→Loosen the thread-making pliers/Reset the thread-making oil cylinder/Loosen the

clamping pliers→Retract the articulated jib. The control flow of automatic making-up process in iron roughneck is shown in Fig. 3(a).

(a)Automatic making-up (b) Automatic breaking-out

Fig.3. The control flow of iron roughneck

Automatic breaking-out process : Automatic centering →Clamp the clamping pliers/Clamp the thread-making pliers→Stretch out the thread-making oil cylinder→Loosen the thread-making pliers/Reset the thread-making oil cylinder/Clamp the rotating screw pliers→Rotating screw motors rotate clockwise → Loosen the rotating screw pliers/Loosen the clamping pliers→Retract the articulated jib. The control flow of automatic breaking-out process in iron roughneck is shown in Fig. 3(b).

5. Experiments

According to the hydraulic system based on the load sensitive proportional multi-way valve and the control system based on the multi-cylinder linkage in iron roughneck, we put up the experimental platform which is shown in Fig.4. The control flow is programmed through a computer, and the program is transferred to the

programmable logic controller, it could achieve the automatic process through the electrical cabinet, the control platform of iron roughneck is shown in Fig.5.

Fig.4. Experimental platform in iron roughneck

Fig.5. The control platform of iron roughneck

Through experimental analysis, the hydraulic system about multi-cylinder linkage which is designed in this paper has the advantages of stable and fast during the movements; the control system in iron roughneck which synthesizes pressure principle, position principle and time principle has the advantages of safety, high reliability, high working efficiency and so on.

6. Conclusions

In this paper, we mainly introduce the working principle of automatic making-up process and automatic breaking-out process in iron roughneck; through the analysis of traditional control system in iron roughneck, we put forward the hydraulic system about multi-cylinder linkage in iron roughneck which adopt the load sensitive and proportional multi-way valve, and the new hydraulic system could improve the working efficiency a lot; we state the pressure principle, position principle and time principle in iron roughneck and carry on comprehensive analysis and comparison, then we put forward the control system based on the integration of pressure principle, position principle

and time principle, and do some related experiments. The control system of iron roughneck which is designed in this paper has the advantages of compact structure, high working efficiency and reliability and so on, it has high utility value and makes a solid foundation for the development of hydraulic system and control system in iron roughneck.

Acknowledgment

This work was financially supported by National Science Foundation of China under Project 60977071, by Science and Technology Department of Jiangsu Province under Project BK2010323, by “333 Talents Engineering” of Jiangsu Province under Project BRA2010131.

References

- (1) Jinhua Yang : “Development of and Market for Global Deep Water Drilling Facilities”, International Petroleum Economics, No. 11, pp. 42-45, 2006
- (2) Bo Zhang : “On Status and Trend of Global Sea Oil Engineering Market”, Journal of Sinopec Management Institute, Vol. 11, No. 2, pp. 20-23, 2009
- (3) Ninghui Li : “Some Suggestions on the Development of Our Workover rigs”, Oil Field Equipment, Vol. 19, No. 3, pp. 33-34, 1990
- (4) Yongjing Yin, and Jinqing Xu : “The Status and Prospects of Workover rigs at home and abroad”, China Petroleum Machinery, Vol. 24, No. A01, pp. 169-173, 1996
- (5) Hongsheng Zhang, Hao Yu, and Jinfeng Zhao : “The Situation and Forecast of Iron Roughneck”, Oil Field Equipment, Vol. 37, No. 1, pp. 12-16, 2008
- (6) Hongsheng Zhang, Hao Yu, Jinfeng Zhao, and Changbing Zhu : “Study of Design scheme of TZG-110 Iron Roughneck”, China Petroleum Machinery, Vol. 36, No. 4, pp. 31-33, 2008
- (7) Yuanchao Zhang, XinglongZhu, Longqin Gao, and Qiyin Chen : “Design of Hydraulic System Based on the Multitandem Valve in Iron Roughneck”, IEEE Computer Society, pp. 1266-1271, 2012